

**REMARKS**

The Office Action indicated that Claims 5 and 10-16 are allowed.

Applicant's invention addresses a problem of graphitized cathode block deterioration, caused by abrasion, during the aluminum refining process. The abrasion of the cathode block causes a requirement of stopping the refining process and replacement of the cathode block with resulting costs.

This problem is solved by creating a unique cathode block that has higher abrasion resistance and increased life span than traditionally manufactured cathode blocks. This invention involves a graphitized cathode block for aluminum refining containing a uniquely formulated calcined coke that can ultimately provide a new abrasion resistant cathode block. The calcined coke is created by combining heavy crude oil and carbon black. Carbon black provides abrasion and wear resistance properties. The combination of carbon black and heavy crude oil to create the calcined coke enables the cathode block to have increased resistivity to abrasion, thus increasing the life span of the cathode block.

The Office Action rejected Claims 1-4 and 6-9 as being anticipated by *Ninomiya et al.* (U.S. Publication 2002/0000373).

“An anticipating reference must describe the patented subject matter with sufficient clarity and detail to establish that the subject matter existed in the prior art and that such existence would be recognized by persons of ordinary skill in the field of the invention. *See In re Spada*, 911 F.2d 705, 708, 15 USPQ2d 1655, 1657 (Fed. Cir. 1990); *Diversitech Corp. v. Century Steps, Inc.*, 850 F.2d 675, 678, 7 USPQ2d 1315, 1317 (Fed. Cir. 1988).”

*Ninomiya* does not recognize an abrasion problem and instead addresses a problem of electrical current concentration buildup at the end portions of a cathode block, which can lead to decreased current efficiency and instability of the smelting pot. (*Ninomiya*, Paragraph 0009). This electrical current problem is solved by introducing a supplemental current

distributor that is attached across the interface of two cathode blocks for dividing the flow of current across adjacent blocks. (*Ninomiya*, Paragraph 0012). The current distributor creates a differential of electrical resistivity, which decreases the current concentration at the end portions of the block. (*Ninomiya*, Paragraph 0015).

*Ninomiya* does not address the problem of cathode block abrasion resistance.

A prior art reference must be considered in its entirety, i.e., as a whole, including portions that would be lead away from the claimed invention. *W.L. Gore & Associates, Inc. v. Garlock, Inc.*, 721 F.2d 1540, 220 USPQ 303 (Fed. Cir. 1983), *cert. denied*, 469 U.S. 851 (1984).

MPEP 2141.02

To evaluate the abrasion resistance problem, the Applicant has described a specific manufacturing process. (Page 9). First, pitch cokes obtained from raw material are used, and a 24% (wt) of binder pitch is added to the pitch coke. *Ninomiya* provides a preferred embodiment where 30 % (wt) coal tar pitch is mixed with 100 parts by weight of calcined petroleum coke. (*Ninomiya*, Paragraph 0047). The coal tar pitch in *Ninomiya* is used as a binder. (*Ninomiya*, Paragraph 0024).

Second, the binder pitch and pitch coke combination is kneaded at 130° C. In *Ninomiya's* preferred embodiment, the pitch and binder combination are kneaded at 150° C. (*Ninomiya*, Paragraph 0047).

Third, the non-graphitized cathode blocks are baked at 1200° C and subsequently graphitized at 2900° C. In *Ninomiya's* preferred embodiment, the non-graphitized cathode blocks are baked up to a temperature of 1000° C, and graphitized at a temperature higher than 2000° C.

Applicant has also provided a comparison of embodiments of cathode blocks versus traditional cathode blocks manufactured by a process similar to *Ninomiya*. (Tables 1-2, Page 9).

Note, the *Ninomiya* preferred embodiment is not formulated with calcined coke containing carbon black. Thus, the *Ninomiya* preferred embodiment is characteristic of manufacturing examples 3 and 5 of Table 1, which correspond to comparison examples 2 and 4 of Table 2, respectively. *Ninomiya* discloses a cathode block with resistivities ranging from 8 to 20  $\mu\Omega\text{m}$ , and thus falls within the specific resistivity ranges listed for comparison examples 2 and 4 in Table 2.

Table 2 also shows Applicant's embodiment examples 1 and 2, which are formulated with calcined coke created by mixing carbon black and heavy crude oil. The embodiment examples 1 and 2 have abrasion amounts (loss of volume) of 28.3 and 32.4 %, respectively, after the cathode blocks have undergone an abrasion test described on Page 9. The comparison examples 2 and 4, which appear representative of the preferred embodiment of *Ninomiya*, have much larger abrasion amounts of 36.6 and 41.3 % by volume, respectively, after undergoing the same abrasion test.

*Ninomiya* states that either a calcined petroleum coke or calcined pitch coke can be combined with a binder to create the raw material used to create the cathode block. *Ninomiya* does not disclose the addition of carbon black to the formulation of this raw material. It is well known in the art that petroleum coke, pitch coke, and carbon black are structurally different materials with their own unique properties, and each is derived in a unique way. See the attached "Recommended Terminology for the Description of Carbon as a Solid" by Fitzer et al., Pure & Appl. Chem. Vol. 67, No. 3, pp. 473-506.

Carbon black is an industrially manufactured colloidal carbon material in the form of spheres. (Fitzer, Page 479). Petroleum coke is a carbonization product of high-boiling heavy residue hydrocarbon fractions obtained in petroleum processing. (Fitzer, Page 499). Calcined pitch coke is derived from coal tar pitch, which is a residue produced by distillation

or heat treatment of coal tar. (Fitzer, Page 485). Thus, calcined petroleum coke and calcined pitch coke are not substitutes or alternatives for carbon black.

The cathode block of the Applicant's invention is created by the addition of carbon black to heavy crude oil during the calcination process. (Page 5, Lines 3-16). *Ninomiya* does not teach nor suggest adding carbon black to the raw material used to create the cathode block. Without the addition of carbon black to the raw materials, *Ninomiya's* cathode block should not exhibit the abrasion resistivity of the Applicant's invention in the final graphitized carbon block product.

While both the Applicant and *Ninomiya* disclose a graphitized cathode block formed using calcined coke, the Applicant's cathode block is formed by using a unique set of raw materials to make the final cathode block more resistant to abrasion than the disclosed embodiment of *Ninomiya*.

Newly added claims 17-23 define further preferred manufacturing methods from allowed Claim 10.

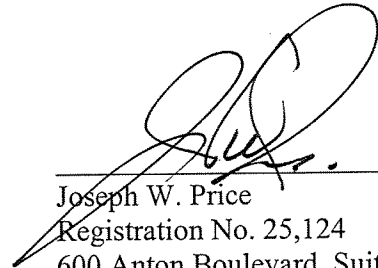
Newly added Claims 21-23 describe abrasion resistivity properties of the graphitized cathode block resulting from a formulation using a unique set of raw materials which includes carbon black and heavy crude oil to create calcined coke. The preferred embodiment of *Ninomiya* does not teach or suggest a cathode block with increased abrasion resistance and two blocks are physically different component materials for creating the finished product with resultant different abrasion properties.

In view of the above comments, it is respectfully submitted the case is now in condition for allowance and early notification of the same is requested.

If the Examiner believes that a telephone interview will help further the prosecution of this case, he is respectfully requested to contact the undersigned attorney at the listed telephone number.

Very truly yours,

**SNELL & WILMER L.L.P.**



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## INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY

INORGANIC CHEMISTRY DIVISION  
COMMISSION ON HIGH TEMPERATURE AND SOLID STATE CHEMISTRY  
SUBCOMMITTEE; TERMINOLOGY OF CARBON SC-1\*

# RECOMMENDED TERMINOLOGY FOR THE DESCRIPTION OF CARBON AS A SOLID

(IUPAC Recommendations 1995)

*Prepared for publication by*

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# Recommended terminology for the description of carbon as a solid (IUPAC Recommendations 1995)

*Synopsis* - This document deals with the recommended terminology for the description of carbon as a solid as used in the science and technology of carbon and graphite materials. The glossary also contains terms describing related materials, such as precursors for the production of carbon materials, and the processes used in their production. In all, 114 terms are defined, and comments and cross-references are added as notes where appropriate.

## PREFACE

Carbon as a solid covers all natural and synthetic substances consisting mainly of atoms of the element carbon, such as single crystals of diamond and graphite, as well as the full variety of carbon and graphite materials.

The terminology used so far is mainly based on technological tradition and on the standardized characterization methods of decades of industrial experience.

Because of the increasing interdisciplinary importance of this group of materials in science and technology, it is obvious that clear definitions of the corresponding terms and modern methods for characterization which are acceptable for all those working in the field are required.

As a first step IUPAC has taken responsibility for recommendations concerning the terminology of "Carbon as a Solid", that are consistent with the scientific nomenclature. These recommendations outlined in the following paper have been prepared by the IUPAC subcommittee SC-1 within the IUPAC commission II /3 (High Temperature and Solid State Chemistry) in cooperation with specialists in carbon science and industry from all over the world.

A total of 114 terms are described in this compilation and the descriptions are supplemented by notes. In so far as is possible, the terms used in the descriptions and notes are self-explanatory but they are cross-referenced where appropriate for ease of use of the glossary.

### *Note:*

A description of FULLERENE is not included in the list of terms since it is anticipated, following consultation with Chemical Abstracts Service, that IUPAC will issue provisional recommendations on Fullerene Nomenclature and Terminology early in 1995.

## LIST OF TERMS

ACETYLENE BLACK  
ACHESON GRAPHITE  
ACTIVATED CARBON  
ACTIVATED CHARCOAL  
AGRANULAR CARBON  
AMORPHOUS CARBON  
ARTIFICIAL GRAPHITE

BAKING  
BINDER  
BINDER COKE  
BROOKS AND TAYLOR STRUCTURE  
IN THE CARBONACEOUS MESOPHASE  
BULK MESOPHASE  
CALCINED COKE

CARBON	GRAPHITE WHISKER
CARBON ARTIFACT	GRAPHITIC CARBON
CARBON BLACK	GRAPHITIZABLE CARBON
CARBON-CARBON COMPOSITE	GRAPHITIZATION
CARBON CENOSPHERES	GRAPHITIZATION HEAT TREATMENT
CARBON CLOTH	GRAPHITIZED CARBON
CARBON ELECTRODE	GREEN COKE
CARBON FELT	HARD AMORPHOUS CARBON FILMS
CARBON FIBRE	HEXAGONAL GRAPHITE
CARBON FIBRE FABRICS	HIGH-PRESSURE GRAPHITIZATION
CARBON FIBRES TYPE HM	HIGHLY ORIENTED PYROLYTIC GRAPHITE
CARBON FIBRES TYPE HT	ISOTROPIC CARBON
CARBON FIBRES TYPE IM	ISOTROPIC PITCH-BASED CARBON FIBRES
CARBON FIBRES TYPE LM (LOW MODULUS)	LAMP BLACK
CARBON FIBRES TYPE UHM	MESOGENIC PITCH
CARBON MATERIAL	MESOPHASE PITCH
CARBON MIX	MESOPHASE PITCH-BASED CARBON FIBRES
CARBON WHISKERS	METALLURGICAL COKE
CARBONACEOUS MESOPHASE	MICROPOROUS CARBON
CARBONIZATION	MPP-BASED CARBON FIBRES
CATALYTIC GRAPHITIZATION	NATURAL GRAPHITE
CHAR	NEEDLE COKE
CHARCOAL	NON-GRAPHITIC CARBON
COAL-DERIVED PITCH COKE	NON-GRAPHITIZABLE CARBON
COAL TAR PITCH	NUCLEAR GRAPHITE
COALIFICATION	PAN-BASED CARBON FIBRES
COKE	PARTICULATE CARBON
COKE BREEZE	PETROLEUM COKE
COLLOIDAL CARBON	PETROLEUM PITCH
DELAYED COKE	PITCH
DELAYED COKING PROCESS	PITCH-BASED CARBON FIBRES
DIAMOND	POLYCRYSTALLINE GRAPHITE
DIAMOND BY CVD	POLYGRANULAR CARBON
DIAMOND-LIKE CARBON FILMS	POLYGRANULAR GRAPHITE
ELECTROGRAPHITE	PREMIUM COKE
EXFOLIATED GRAPHITE	PUFFING
FIBROUS ACTIVATED CARBON	PUFFING INHIBITOR
FIBROUS CARBON	PYROLYTIC CARBON
FILAMENTOUS CARBON	PYROLYTIC GRAPHITE
FILLER	RAW COKE
FILLER COKE	RAYON-BASED CARBON FIBRES
FLUID COKE	REGULAR COKE
FULLERENES	RHOMBOHEDRAL GRAPHITE
FURNACE BLACK	SEMICOKE
GAS PHASE-GROWN CARBON FIBRES	SOOT
GLASS-LIKE CARBON	SPHERICAL CARBONACEOUS MESOPHASE
GRANULAR CARBON	STABILIZATION TREATMENT OF THERMO
GRAPHENE LAYER	PLASTIC PRECURSOR FIBRES FOR
GRAPHITE	CARBON FIBRES
GRAPHITE ELECTRODE	STRESS GRAPHITIZATION
GRAPHITE FIBRES	SYNTHETIC GRAPHITE
GRAPHITE MATERIAL	THERMAL BLACK



## DESCRIPTIONS OF THE TERMS

### ACETYLENE BLACK

*Description:*

ACETYLENE BLACK is a special type of CARBON BLACK formed by an exothermic decomposition of acetylene. It is characterized by the highest degree of aggregation and crystalline orientation when compared with all types of CARBON BLACK:

See: CARBON BLACK

*Note:*

ACETYLENE BLACK must not be confused with the CARBON BLACK produced as a by-product during the production of acetylene in the electric arc process.

See: CARBON BLACK

### ACHESON GRAPHITE

*Description:*

ACHESON GRAPHITE is a SYNTHETIC GRAPHITE made by the Acheson process.

See: SYNTHETIC GRAPHITE

*Note:*

Reference to Acheson in combination with SYNTHETIC GRAPHITE honours the inventor of the first technical GRAPHITIZATION. Today the term ACHESON GRAPHITE, however, is of historical interest only because it no longer covers the plurality of SYNTHETIC GRAPHITE.

See: SYNTHETIC GRAPHITE

### ACTIVATED CARBON

*Description:*

ACTIVATED CARBON is a porous CARBON MATERIAL, a CHAR which has been subjected to reaction with gases, sometimes with the addition of chemicals, e.g.  $\text{ZnCl}_2$ , before, during or after CARBONIZATION in order to increase its adsorptive properties.

See: CARBON MATERIAL  
CARBONIZATION  
CHAR

*Notes:*

ACTIVATED CARBONS have a large adsorption capacity, preferably for small molecules, and are used for purification of liquids and gases. By controlling the process of CARBONIZATION and activation, a variety of active carbons having different porosity can be obtained. ACTIVATED CARBONS are used mainly in granular and powdered forms, but can also be produced in textile form by controlled CARBONIZATION and activation of textile fibres. Other terms used in the literature: active carbons, active charcoals.

See: CARBONIZATION

### ACTIVATED CHARCOAL

*Description:*

ACTIVATED CHARCOAL is a traditional term for ACTIVATED CARBON.

See: ACTIVATED CARBON

### AGRANULAR CARBON

*Description:*

AGRANULAR CARBON is a monogranular or monolithic CARBON MATERIAL with homogeneous microstructure which does not exhibit any structural components distinguishable by optical microscopy.

See: CARBON MATERIAL

*Notes:*

The above definition of a homogeneous microstructure does not pertain to pores and structural components which may be visible by contrast differences in optical microscopy with

polarized light. As a consequence, GLASS-LIKE CARBON with visible pores is still an AGRANULAR CARBON. The same is true, for instance, for PYROLYTIC CARBON with preferred orientation, such as conical or lamellar structures, visible in optical microscopy with polarized light. The use of the term AGRANULAR CARBON is not restricted to bulk materials of a minimum size. Only PARTICULATE CARBON should be excluded even if the isolated particles exhibit a homogeneous microstructure.

See: GLASS-LIKE CARBON  
PARTICULATE CARBON  
PYROLYTIC CARBON

## AMORPHOUS CARBON

### Description:

AMORPHOUS CARBON is a CARBON MATERIAL without long-range crystalline order. Short-range order exists, but with deviations of the interatomic distances and/or interbonding angles with respect to the graphite lattice as well as to the diamond lattice.

See: CARBON MATERIAL  
DIAMOND-LIKE CARBON

### Notes:

The term AMORPHOUS CARBON is restricted to the description of CARBON MATERIALS with localized  $\pi$ -electrons as described by P.W.ANDERSON [*Phys.Rev.* **109**, 1492 (1958)]. Deviations in the C-C distances greater than 5% (i.e.  $\pm \Delta x/x_0 > 0.05$ , where  $x_0$  is the interatomic distance in the crystal lattice for the  $sp^2$  as well as for the  $sp^3$  configuration) occur in such materials, as well as deviations in the bond angles because of the presence of "dangling bonds".

Above description of AMORPHOUS CARBON is not applicable to CARBON MATERIALS with two-dimensional structural elements present in all pyrolysis residues of carbon compounds as polyaromatic layers with a nearly ideal interatomic distance of  $a = 142$  pm and an extension greater than 1000 pm.

See: CARBON MATERIAL

## ARTIFICIAL GRAPHITE

### Description:

The term ARTIFICIAL GRAPHITE is often used in place of SYNTHETIC GRAPHITE.

See: SYNTHETIC GRAPHITE

### Note:

This term is not recommended.

## BAKING

### Description:

The process in which the carbonaceous BINDER, usually COAL TAR PITCH or PETROLEUM PITCH, as part of a shaped CARBON MIX is converted to CARBON yielding a rigid carbon body by the slow application of heat. The process can take as little as 14 days in coarse-grained, electrothermic grades (low binder level) and as long as 36 days in ultra-fine-grained, speciality grades (high binder level). The final baking temperature can be in the range of 1100 K - 1500 K, depending on the grade.

See: BINDER  
CARBON  
COAL TAR PITCH  
PETROLEUM PITCH

## BINDER

### Description:

A BINDER is usually a COAL TAR PITCH or PETROLEUM PITCH (but may include thermosetting resins or MESOPHASE PITCH powders) which, when mixed with a BINDER COKE or a FILLER, constitutes a CARBON MIX. This is used in preparation of the formation of shaped green bodies and subsequently CARBON ARTIFACTS.

See: BINDER COKE  
CARBON ARTIFACT  
CARBON MIX  
COAL TAR PITCH  
MESOPHASE PITCH  
PETROLEUM PITCH  
PITCH

### **BINDER COKE**

*Description:*

BINDER COKE is a constituent of a carbon (or ceramic) artifact resulting from CARBONIZATION of the binder during baking.

See: CARBONIZATION

*Note:*

PITCHES are mainly used as binders, i.e. as precursors for BINDER COKES, but the term BINDER should include any carbonaceous binder material, for example thermosetting resins such as poly(furfuryl alcohol) or phenolics and similar compounds which may form a CHAR during CARBONIZATION.

See: CARBONIZATION  
CHAR

### **BROOKS AND TAYLOR STRUCTURE IN THE CARBONACEOUS MESOPHASE**

*Description:*

The BROOKS AND TAYLOR STRUCTURE IN THE CARBONACEOUS MESOPHASE refers to the structure of the anisotropic spheres which precipitate from isotropic PITCH during pyrolysis. The structure of the spheres consists of a lamellar arrangement of aromatic molecules in parallel layers which are perpendicular to the polar axis of the sphere and which are perpendicular to the mesophase-isotropic phase interface.

*Note:*

The term BROOKS AND TAYLOR STRUCTURE is recommended to describe the particular lamellar morphology of the spherules most commonly precipitated from pyrolyzed PITCH. The term honours the workers who first recognized the significance of CARBONACEOUS MESOPHASE to carbon science and technology and who first defined this spherical morphology. The term BROOKS AND TAYLOR STRUCTURE does not cover all structures found in the spherical mesophase, because other lamellar arrangements have been observed.

See: CARBONACEOUS MESOPHASE  
PITCH

### **BULK MESOPHASE**

*Description:*

BULK MESOPHASE is a continuous anisotropic phase formed by coalescence of mesophase spheres. BULK MESOPHASE retains fluidity and is deformable in the temperature range up to about 770 K, and transforms into GREEN COKE by further loss of hydrogen or low-molecular-weight species.

See: GREEN COKE

*Note:*

This BULK MESOPHASE can sometimes be formed directly from the isotropic PITCH without observation of intermediate spheres.

See: PITCH

**CALCINED COKE***Description:*

CALCINED COKE is a PETROLEUM COKE or COAL-DERIVED PITCH COKE obtained by heat treatment of GREEN COKE to about 1600 K. It will normally have a hydrogen content of less than 0.1 wt. %.

See: COAL-DERIVED PITCH COKE  
GREEN COKE  
PETROLEUM COKE

*Note:*

CALCINED COKE is the main raw material for the manufacture of POLYGRANULAR CARBON and POLYGRANULAR GRAPHITE products (e.g. CARBON and GRAPHITE ELECTRODES).

See: CARBON ELECTRODE  
POLYGRANULAR CARBON  
POLYGRANULAR GRAPHITE

**CARBON***Description:*

CARBON is the element number 6 of the Periodic Table of Elements (electronic ground state  $1s^2 2s^2 2p^2$ ).

*Note:*

For description of the various types of CARBON AS A SOLID the term CARBON should be used only in combination with an additional noun or a clarifying adjective.

See: AMORPHOUS CARBON  
CARBON FIBRES  
CARBON MATERIAL  
GLASS-LIKE CARBON  
GRAPHITIC CARBON  
NON-GRAPHITIC CARBON  
PYROLYTIC CARBON

**CARBON ARTIFACT***Description:*

CARBON ARTIFACT means an "artificially produced" solid body which consists mainly of carbonaceous material in a distinct shape.

*Note:*

Sometimes this term is also used for artificially (in the sense of technically) produced non-shaped CARBON MATERIALS such as COKE, blacks, etc. This application of the term CARBON ARTIFACT is not recommended. Synonyms to the term CARBON ARTIFACT are: "artificial carbon article" or "artificial carbon body".

See: CARBON MATERIAL  
COKE

**CARBON BLACK***Description:*

CARBON BLACK is an industrially manufactured COLLOIDAL CARBON material in the form of spheres and of their fused aggregates with sizes below 1000 nm.

See: COLLOIDAL CARBON

*Notes:*

CARBON BLACK is a commercial product manufactured by thermal decomposition, including detonation, or by incomplete combustion of carbon hydrogen compounds and has a well-defined morphology with a minimum content of tars or other extraneous materials.

For historical reasons, however, CARBON BLACK is popularly but incorrectly regarded as a form of SOOT. In fact, in many languages, the same word is used to designate both materi-

als. CARBON BLACK is manufactured under controlled conditions, whereas SOOT is randomly formed. They can be distinguished on the basis of tar, ash content and impurities. Attempts in the literature to create a general term, "aciniform carbon", which would cover both CARBON BLACK and SOOT, is not yet generally accepted.

See: SOOT

### CARBON-CARBON COMPOSITE

*Description:*

A CARBON-CARBON COMPOSITE is a CARBON FIBRE-reinforced carbon matrix material. The carbon matrix phase is typically formed by solid, liquid or gaseous pyrolysis of an organic precursor material. The matrix is either a GRAPHITIZABLE CARBON or NON-GRAPHITIZABLE CARBON, and the carbonaceous reinforcement is fibrous in form. The composite may also contain other components in particulate or fibrous forms.

See: CARBON FIBRE  
GRAPHITIZABLE CARBON  
NON-GRAPHITIZABLE CARBON

### CARBON CENOSPHERES

*Description:*

CARBON CENOSPHERES are porous or hollow carbonaceous sphere-like particles (frequently in the size range of a few to several hundreds of  $\mu\text{m}$  diameter) formed during pyrolysis, also in the course of combustion, of carbonaceous liquid droplets (e.g. heavy fuel) or solid particles (e.g. coal).

### CARBON CLOTH

*Description:*

CARBON CLOTH is a textile material consisting of CARBON FIBRES oriented at least in two directions.

See: CARBON FIBRES

*Note:*

CARBON CLOTH is not necessarily woven.

### CARBON ELECTRODE

*Description:*

A CARBON ELECTRODE is an electrode for an electrical application. In its green state it comprises granular carbon material bound with pitch. The GRANULAR CARBON material may be either NEEDLE COKE, fine-grained or isotropic coke or reclaimed GRAPHITE powder. Electrodes for use in steel production can only be manufactured from NEEDLE COKE, and the green electrodes are fired at temperatures above around 2800 K to produce highly graphitic electrodes (GRAPHITE ELECTRODES). The other granular carbon materials may be used for aluminium electrodes where the duty is not so severe, and the green electrodes are generally fired to lower temperatures.

See: GRANULAR CARBON  
GRAPHITIC CARBON  
GRAPHITIZATION HEAT TREATMENT  
ISOTROPIC CARBON  
NEEDLE COKE

*Note:*

In both cases it is essential that the GRANULAR CARBONS and the PITCH binders used in the production of the green electrodes have a low sulfur content as the release of sulfur during the high-temperature firing can lead to the production of significant porosity.

See: PUFFING

**CARBON FELT***Description:*

CARBON FELT is a textile material consisting of, in approximation, randomly oriented and intertwined CARBON FIBRES.

See: CARBON FIBRES

*Note:*

CARBON FELTS are usually fabricated by CARBONIZATION of organic felts but they can also be produced from short CARBON FIBRES.

See: CARBON FIBRES  
CARBONIZATION

**CARBON FIBRE***Description:*

CARBON FIBRES are fibres (filaments, tows, yarns, rovings) consisting of at least 92% (mass fraction) CARBON, usually in the NON-GRAPHITIC state.

See: CARBON  
NON-GRAPHITIC CARBON

*Notes:*

CARBON FIBRES are fabricated by pyrolysis of organic precursor fibres or by growth from gaseous hydrocarbons. The use of the term GRAPHITE FIBRES instead of CARBON FIBRES as often observed in the literature is incorrect and should be avoided. The term GRAPHITE FIBRES is justified only if three-dimensional crystalline order is confirmed, e.g. by X-ray diffraction measurements.

See: GRAPHITE FIBRES

**CARBON FIBRE FABRICS***Description:*

CARBON FIBRE FABRICS are woven textile materials made of CARBON FIBRES.

See: CARBON FIBRES

**CARBON FIBRES TYPE HM***Description:*

CARBON FIBRES TYPE HM (HIGH MODULUS) are CARBON FIBRES with a value of Young's modulus (tensile modulus) larger than 300 GPa (nearly 30% of the  $C_{11}$  elastic constant of a graphite single crystal).

See: CARBON FIBRES

*Notes:*

The level of the tensile modulus of CARBON FIBRES is controlled by the degree of preferred orientation of the layer planes in the direction parallel to the fibre axis.  $C_{11}$ , the elastic constant of graphite single crystals in the direction of the layer planes is  $1060 \pm 20$  GPa.

In general, the ratio of tensile strength to tensile modulus is smaller than  $1 \cdot 10^{-2}$  for CARBON FIBRES TYPE HM (but the tensile strength is influenced by flaws in the fibres and may be improved in the future).

CARBON FIBRES TYPE UHM (ULTRA-HIGH MODULUS) have moduli of elasticity in excess of 600 GPa, surpassing 50% of the theoretical  $C_{11}$  number. Such high values of Young's modulus can be achieved most readily in MESOPHASE PITCH-BASED CARBON FIBRES (MPP-based carbon fibres).

See: CARBON FIBRES

**CARBON FIBRES TYPE HT***Description:*

CARBON FIBRES TYPE HT are CARBON FIBRES with values of Young's modulus between 150 and 275 to 300 GPa. The term HT, referring to high tensile strength, was early applied because fibres of this type display the highest tensile strengths.

See: CARBON FIBRES

*Notes:*

The disposition of boundaries between the fibre types is somewhat arbitrary.

For CARBON FIBRES TYPE HT, the values of the strength-to-stiffness ratio are typically larger than  $1.5 \cdot 10^{-2}$ . The tensile strength of CARBON FIBRES is flaw-controlled, however, and therefore the measured values increase strongly as the diameter of the filaments is decreased.

See: CARBON FIBRES  
CARBON FIBRES TYPE IM

**CARBON FIBRES TYPE IM***Description:*

The CARBON FIBRES TYPE IM (INTERMEDIATE MODULUS) are related to CARBON FIBRES TYPE HT because of the comparable values of tensile strength, but are characterized by greater stiffness (Young's modulus up to approximately 35% of the theoretical  $C_{11}$  value).

See: CARBON FIBRES  
CARBON FIBRES TYPE HT

*Notes:*

The tensile modulus (Young's modulus) varies between ca. 275 and 350 GPa, but the disposition of the boundaries is somewhat arbitrary. The relatively high ratio of tensile strength to tensile modulus, typically above  $1 \cdot 10^{-2}$ , in CARBON FIBRES TYPE IM, in spite of an increase of Young's modulus, requires a further increase of strength, which is achievable by a significant reduction of the monofilament diameter down to about 5  $\mu\text{m}$ . Such small filament diameters are typical of CARBON FIBRES TYPE IM.

**CARBON FIBRES TYPE LM***Description:*

CARBON FIBRES TYPE LM (LOW MODULUS) are CARBON FIBRES with isotropic structure, tensile modulus values as low as 10% of the  $C_{11}$  values of the graphite single crystal, and low strength values.

See: CARBON FIBRES

*Notes:*

The term CARBON FIBRES TYPE LM is sometimes used for various types of isotropic CARBON FIBRES known as PITCH-BASED or RAYON-BASED CARBON FIBRES that have not been subjected to hot-stretching. Such fibres are not used for reinforcement purposes in high-performance composites.

See: CARBON FIBRES  
PITCH-BASED CARBON FIBRES  
RAYON-BASED CARBON FIBRES

**CARBON FIBRES TYPE UHM***Description:*

CARBON FIBRES TYPE UHM (ULTRA-HIGH MODULUS) designates a class of CARBON FIBRES having very high values of Young's modulus larger than 600 GPa (*i.e.* greater than 55% of the theoretical  $C_{11}$  value of GRAPHITE).

See: CARBON FIBRE  
CARBON FIBRE TYPE HM  
GRAPHITE

**CARBON MATERIAL***Description:*

CARBON MATERIAL is a solid high in content of the element CARBON and structurally in a NON-GRAPHITIC state.

See: CARBON  
NON-GRAPHITIC CARBON

**Notes:**

The use of the term CARBON as a short term for a material consisting of NON-GRAPHITIC CARBON is incorrect. The use of the term CARBON without a second noun or a clarifying adjective should be restricted to the chemical element carbon. The term CARBON can be used in combination with other nouns or clarifying adjectives for special types of CARBON MATERIALS (CARBON ELECTRODE, CARBON FIBRES, PYROLYTIC CARBON, GLASS-LIKE CARBON and others).

See: CARBON  
CARBON ELECTRODE  
CARBON FIBRES  
GLASS-LIKE CARBON  
NON-GRAPHITIC CARBON  
PYROLYTIC CARBON

**CARBON MIX***Description:*

CARBON MIX is a mixture of FILLER COKE, e.g. grains and/or powders of solid CARBON MATERIALS, and a carbonaceous BINDER and selected additives, prepared in heated mixers at temperatures in the range of 410 K - 445 K as a preliminary step for the formation of shaped green bodies.

See: BINDER  
CARBON MATERIAL  
FILLER COKE

**CARBON WHISKERS***Description:*

See: GRAPHITE WHISKERS

**CARBONACEOUS MESOPHASE***Description:*

CARBONACEOUS MESOPHASE is a liquid-crystalline state of PITCH which shows the optical birefringence of disc-like (discotic) nematic liquid crystals. It can be formed as an intermediate phase during thermolysis (pyrolysis) of an isotropic molten PITCH or by precipitation from PITCH fractions prepared by selective extraction. Generally, the spherical mesophase precipitated from a pyrolyzing PITCH has the BROOKS AND TAYLOR STRUCTURE. With continuous heat treatment the CARBONACEOUS MESOPHASE coalesces to a state of BULK MESOPHASE before solidification to GREEN COKE with further loss of hydrogen or low-molecular-weight compounds.

See: BROOKS AND TAYLOR STRUCTURE IN THE CARBONACEOUS  
MESOPHASE  
BULK MESOPHASE  
GREEN COKE  
PITCH

**Notes:**

In the formation of CARBONACEOUS MESOPHASE by thermolysis (pyrolysis) of isotropic molten PITCH, the development of a liquid-crystalline phase is accompanied by simultaneous aromatic polymerization reactions. The reactivity of PITCH with increasing heat treatment temperature and its thermosetting nature are responsible for the lack of a true reversible thermotropic phase transition for the BULK MESOPHASE in most PITCHES. Due to its glass-like nature most of the liquid-crystalline characteristics are retained in the super-cooled solid state.

See: BROOKS AND TAYLOR STRUCTURE IN THE CARBONACEOUS  
MESOPHASE  
BULK MESOPHASE  
PITCH



**CARBONIZATION***Description:*

CARBONIZATION is a process by which solid residues with increasing content of the element carbon are formed from organic material usually by pyrolysis in an inert atmosphere.

*Notes:*

As with all pyrolytic reactions, CARBONIZATION is a complex process in which many reactions take place concurrently such as dehydrogenation, condensation, hydrogen transfer and isomerization. It differs from COALIFICATION in that its reaction rate is faster by many orders of magnitude. The final pyrolysis temperature applied controls the degree of CARBONIZATION and the residual content of foreign elements, e.g. at  $T \sim 1200$  K the carbon content of the residue exceeds a mass fraction of 90 wt.%, whereas at  $T \sim 1600$  K more than 99 wt.% carbon is found.

See: CALCINED COKE  
COALIFICATION

**CATALYTIC GRAPHITIZATION***Description:*

CATALYTIC GRAPHITIZATION refers to a transformation of NON-GRAPHITIC CARBON into GRAPHITE by heat treatment in the presence of certain metals or minerals.

See: GRAPHITE  
GRAPHITIZATION  
NON-GRAPHITIC CARBON

*Notes:*

CATALYTIC GRAPHITIZATION gives a fixed degree of GRAPHITIZATION at lower temperature and/or for a shorter heat treatment time than in the absence of the catalytic additives (or a higher degree of GRAPHITIZATION at fixed heat treatment conditions). Often it involves dissolution of CARBON and precipitation of GRAPHITE at the catalyst particles so that NON-GRAPHITIZING CARBONS can be graphitized by this procedure.

See: CARBON  
GRAPHITE  
GRAPHITIZATION  
NON-GRAPHITIZING CARBON

**CHAR***Description:*

CHAR is a solid decomposition product of a natural or synthetic organic material.

*Notes:*

If the precursor has not passed through a fluid stage, CHAR will retain the characteristic shape of the precursor (although becoming of smaller size). For such materials the term "pseudomorphous" has been used. Some simple organic compounds, e.g. sugar, melt at an early stage of decomposition and then polymerize during CARBONIZATION to produce CHARS.

See: CARBONIZATION

**CHARCOAL***Description:*

CHARCOAL is a traditional term for a CHAR obtained from wood, peat, coal or some related natural organic materials.

See: CHAR

*Note:*

CHARCOAL has highly reactive inner surfaces and a low sulfur content. It has or has had, therefore, a variety of uses, e.g. in ferrous metallurgy and for gun-powder (minor uses: medical purpose and paint materials).

**COAL-DERIVED PITCH COKE***Description:*

COAL-DERIVED PITCH COKE is the primary industrial solid CARBONIZATION product obtained from COAL TAR PITCH, and is mainly produced in chamber or DELAYED COKING PROCESSES.

See: CARBONIZATION  
COAL TAR PITCH  
DELAYED COKING PROCESS

*Note:*

COAL-DERIVED PITCH COKE, although it exhibits a pregraphitic microstructure, has often a lower graphitizability than PETROLEUM COKE. Fractions of COAL TAR PITCHES (obtained by extraction or filtration) may form COKES with needle-like structures and have an improved graphitizability. The usually lower graphitizability compared to PETROLEUM COKE is due to an inhibition of mesophase growth because of chemical and physical differences of the cokes.

See: COAL TAR PITCHES  
COKE  
PETROLEUM COKE

**COAL TAR PITCH***Description:*

COAL TAR PITCH is a residue produced by distillation or heat treatment of coal tar. It is a solid at room temperature, consists of a complex mixture of numerous predominantly aromatic hydrocarbons and heterocyclics, and exhibits a broad softening range instead of a defined melting temperature.

*Note:*

The hydrogen aromaticity in COAL TAR PITCH (ratio of aromatic to total content of hydrogen atoms) varies from 0.7 to 0.9.

**COALIFICATION***Description:*

COALIFICATION is a geological process of formation of materials with increasing content of the element carbon from organic materials that occurs in a first, biological stage into peats, followed by a gradual transformation into coal by action of moderate temperature (about 500 K) and high pressure in a geochemical stage.

*Notes:*

COALIFICATION is a dehydrogenation process with a reaction rate slower by many orders of magnitude than that of CARBONIZATION. Some specific reactions approach completion before others have started. The dehydrogenation remains incomplete. The degree of COALIFICATION reached by an organic material in the process of COALIFICATION increases progressively and can be defined by means of the measured C/H ratio and of the residual contents of oxygen, sulfur and nitrogen.

See: CARBONIZATION

**COKE***Description:*

COKE is a solid high in content of the element carbon and structurally in the NON-GRAPHITIC state. It is produced by pyrolysis of organic material which has passed, at least in part, through a liquid or liquid-crystalline state during the CARBONIZATION process. COKE can contain mineral matter.

See: CARBONIZATION  
NON-GRAPHITIC CARBON

*Notes:*

As some parts, at least, of the CARBONIZATION product have passed through a liquid or liquid-crystalline state, the resulting NON-GRAPHITIC CARBON is of the graphitizable variety. From a structural viewpoint, the term COKE characterizes the state of GRAPHITIZABLE CARBON before the beginning of GRAPHITIZATION.

See: CARBONIZATION  
GRAPHITIZABLE CARBON  
GRAPHITIZATION  
NON-GRAPHITIC CARBON

**COKE BREEZE***Description:*

COKE BREEZE is a by-product of COKE manufacture; it is the residue from the screening of heat-treated COKE; the particle size is less than 10 mm. Generally, COKE BREEZE has a volatile matter content of <3 wt. %.

See: COKE

**COLLOIDAL CARBON***Description:*

COLLOIDAL CARBON is a PARTICULATE CARBON with particle sizes below ca. 1000 nm in at least one dimension.

See: PARTICULATE CARBON

*Note:*

COLLOIDAL CARBON exists in several morphologically distinct forms.

See: PARTICULATE CARBON  
CARBON BLACK

**DELAYED COKE***Description:*

DELAYED COKE is a commonly used term for a primary CARBONIZATION product (GREEN or RAW COKE) from high-boiling hydrocarbon fractions (heavy residues of petroleum or coal processing) produced by the DELAYED COKING PROCESS.

See: CARBONIZATION  
DELAYED COKING PROCESS  
GREEN or RAW COKE

*Notes:*

DELAYED COKE has, with only a few exceptions, a better graphitizability than COKES produced by other coking processes even if the same feedstock is used. DELAYED COKE contains a mass fraction of volatile matter between 4 and 15 wt. % which can be released during heat treatment.

See: COKE  
DELAYED COKING PROCESS

**DELAYED COKING PROCESS***Description:*

DELAYED COKING PROCESS is a thermal process which increases the molecular aggregation or association in petroleum-based residues or COAL TAR PITCHES leading to extended mesophase domains. This is achieved by holding them at an elevated temperature (usually 750 K - 765 K) over a period of time (12 to 36 hours). It is performed in a coking drum and is designed to ultimately produce DELAYED COKE. The feed is rapidly preheated in a tubular furnace to about 760 K.

See: COAL TAR PITCH  
DELAYED COKE

*Notes:*

NEEDLE COKE is the premium product of the DELAYED COKING PROCESS. It is generally produced from highly aromatic residues from, for instance, the steam cracking of gas oil. Its appearance and preferred orientation of the GRAPHENE LAYERS is the consequence of the evolved gaseous products percolating through the mesophase which must not have too high a viscosity. A close control of temperature, time, and feedstock is essential. Lower grades, for instance ISOTROPIC COKES, are used for CARBON ELECTRODES applied, for example, in the production of aluminium.

See: ISOTROPIC CARBON  
NEEDLE COKE

**DIAMOND***Description:*

DIAMOND is an allotropic form of the element carbon with cubic structure (space group  $Oh^7 - Fd3m$ ) which is thermodynamically stable at pressures above 6 GPa at room temperature and metastable at atmospheric pressure. At low pressures DIAMOND converts rapidly to GRAPHITE at temperatures above 1900 K in an inert atmosphere. The chemical bonding between the carbon atoms is covalent with  $sp^3$  hybridization.

See: CARBON  
GRAPHITE

*Note:*

There is also a hexagonal diamond-like structure of the element CARBON (Lonsdaleite).

See: CARBON

**DIAMOND BY CVD***Description:*

DIAMOND BY CVD (Chemical Vapour Deposition) is formed as crystals or as films from various gaseous hydrocarbons or other organic molecules in the presence of activated, atomic hydrogen. It consists of  $sp^3$ -hybridized carbon atoms with the three-dimensional crystalline structure of the diamond lattice.

See: DIAMOND-LIKE CARBON FILMS

*Notes:*

"CVD diamond" or "low-pressure diamond" are synonyms of the term DIAMOND BY CVD. DIAMOND BY CVD can be prepared in a variety of ways. Deposition parameters are: total (low) pressure, partial hydrogen pressure, precursor molecules in the gas phase, temperature for activation of the hydrogen and that of the surface of the underlying substrate. The energy supply for the hydrogen activation may be, for instance: heat, radio frequency, microwave excitation (plasma deposition) or accelerated ions (e.g.  $Ar^+$  ions). CVD diamond has also been obtained at atmospheric pressure from oxyacetylene torches and by other flame-based methods.

Often CVD carbon films consist of a mixture of  $sp^2$ - and  $sp^3$ -hybridized carbon atoms and do not have the three-dimensional structure of the DIAMOND lattice. In this case they should be called HARD AMORPHOUS CARBON or DIAMOND-LIKE CARBON FILMS.

See: DIAMOND-LIKE CARBON FILMS

**DIAMOND-LIKE CARBON FILMS***Description:*

DIAMOND-LIKE CARBON (DLC) FILMS are hard, amorphous films with a significant fraction of  $sp^3$ -hybridized carbon atoms and which can contain a significant amount of hydrogen. Depending on the deposition conditions, these films can be fully amorphous or contain DIAMOND crystallites. These materials are not called DIAMOND unless a full three-dimensional crystalline lattice of DIAMOND is proven.

See: DIAMOND

*Notes:*

Diamond-like films without hydrogen can be prepared by carbon ion beam deposition, ion-assisted sputtering from GRAPHITE or by laser ablation of GRAPHITE. DIAMOND-LIKE CARBON FILMS containing significant contents of hydrogen are prepared by chemical vapour deposition. The hydrogen content is usually over 25 atomic %. The deposition parameters are (low) total pressure, hydrogen partial pressure, precursor molecules, and plasma ionisation. The plasma activation can be radio frequency, microwave, or  $\text{Ar}^+$  ions. High ionisation favours amorphous films while high atomic hydrogen contents favour DIAMOND crystallite formation. Because of the confusion about structure engendered by the term DIAMOND-LIKE CARBON FILMS, the term HARD AMORPHOUS CARBON has been suggested as a synonym.

**ELECTROGRAPHITE***Description:*

ELECTROGRAPHITE is a SYNTHETIC GRAPHITE made by electrical heating of GRAPHITIZABLE CARBON.

See: SYNTHETIC GRAPHITE

**EXFOLIATED GRAPHITE***Description:*

EXFOLIATED GRAPHITE is the product of very rapid heating (or flash heating) of graphite intercalation compounds, such as graphite hydrogen sulfate of relatively large particle diameter (flakes). The vaporizing intercalated substances force the graphite layers apart. The EXFOLIATED GRAPHITE assumes an accordion-like shape with an apparent volume often hundreds of times that of the original graphite flakes.

*Notes:*

EXFOLIATED GRAPHITE is usually prepared from well-crystallized NATURAL flake GRAPHITE. It is used for the production of graphite foils. EXFOLIATED GRAPHITE is different from the deflagration product of graphite oxide (graphitic acid).

See: NATURAL GRAPHITE

**FIBROUS ACTIVATED CARBON***Description:*

FIBROUS ACTIVATED CARBON is an ACTIVATED CARBON in the form of fibres, filaments, yarns or rovings and fabrics or felts. Such fibers differ from CARBON FIBRES used for reinforcement purposes in composites by their high surface area, high porosity and low mechanical strength.

See: ACTIVATED CARBON  
CARBON FIBRES

*Note:*

Sometimes fabrics of FIBROUS ACTIVATED CARBON are named CHARCOAL cloths; a more precise term is "activated carbon cloth".

See: ACTIVATED CHARCOAL  
CHARCOAL

**FIBROUS CARBON***Description:*

See: FILAMENTOUS CARBON

**FILAMENTOUS CARBON***Description:*

FILAMENTOUS CARBON is a carbonaceous deposit from gaseous carbon compounds, consisting of filaments grown by the catalytic action of metal particles.

**Notes:**

In general, such deposits are obtained at pressures of <100 kPa in the temperature region 600 K to 1300 K on metals such as iron, cobalt or nickel.

Typical filaments consist of a duplex structure, a relatively oxidation-resistant skin surrounding a more easily oxidizable core, with a metal particle located at the growing end of the filament. They generally range from 0.01 to 0.5  $\mu\text{m}$  in diameter and up to 10  $\mu\text{m}$  in length.

In some systems, the metal particles are located in the middle of the filaments, and there are also examples where several filaments originate from a single particle.

The filaments may be produced in different conformations, such as helical, twisted and straight.

See: R.T.K.Baker and P.S.Harris, in: *Chemistry and Physics of Carbon*, Vol.14, edited by P.L.Walker, Jr. and P.A.Thrower, Marcel Dekker, New York, 1978, pp. 83-165.

**FILLER***Description:*

FILLER (also called GRIST) is a petroleum- or coal-based coke fraction of a green, carbon mix or formulation. Coarse particles, >0.425 mm, are sometimes referred to as tailings; fine particles, <0.074 mm, are referred to as flour. GRAPHITE flour is also used as a filler.

**FILLER COKE***Description:*

FILLER COKE is the main constituent of a carbon artifact, introduced as solid component (predominantly in the form of PARTICULATE CARBON) into the "CARBON MIX" from which POLYGRANULAR CARBON and GRAPHITE materials are obtained by heat treatment.

See: CARBON MATERIAL  
CARBON MIX  
GRAPHITE MATERIAL  
PARTICULATE CARBON  
POLYGRANULAR CARBON  
POLYGRANULAR GRAPHITE

*Note:*

FILLER COKE is not necessarily the only, but it is commonly the most important FILLER material used in a "CARBON MIX" which consists of FILLER and binder.

See: CARBON MIX  
FILLER

**FLUID COKE***Description:*

FLUID COKE is the CARBONIZATION product of high-boiling hydrocarbon fractions (heavy residues of petroleum or coal processing) produced by the fluid coking process.

See: CARBONIZATION

*Notes:*

FLUID COKE consists of spherulitic grains with a spherical layer structure and is generally less graphitizable than DELAYED COKE. Therefore, it is not suitable as FILLER COKE for POLYGRANULAR GRAPHITE products and is also less suitable for POLYCRYSTALLINE CARBON products. Because of its isotropy it is less suitable to produce an anisotropic SYNTHETIC GRAPHITE. All COKES contain a fraction of matter that can be released as volatiles during heat treatment. This mass fraction, the so-called volatile matter, is in the case of FLUID COKE about 6 wt. %.

See: COKE  
DELAYED COKE  
FILLER COKE  
POLYGRANULAR GRAPHITE  
cont.

POLYCRYSTALLINE CARBON  
SYNTHETIC GRAPHITE

**FULLERENES**

See: Note to the preface.

**FURNACE BLACK**

*Description:*

FURNACE BLACK is a type of CARBON that is produced industrially in a furnace by incomplete combustion in an adjustable and controllable process that yields a wide variety of properties within the product.

See: CARBON BLACK

*Note:*

The most widely employed industrial process for CARBON BLACK production is the furnace process.

See: CARBON BLACK

**GAS PHASE-GROWN CARBON FIBRES**

*Description:*

GAS-PHASE-GROWN CARBON FIBRES are CARBON FIBRES grown in an atmosphere of hydrocarbons with the aid of fine particulate solid catalysts such as iron or other transition metals and consisting of GRAPHITIZABLE CARBON.

See: CARBON FIBRES  
GRAPHITIZABLE CARBON

*Notes:*

GAS PHASE-GROWN CARBON FIBRES transform during GRAPHITIZATION HEAT TREATMENT into GRAPHITE FIBRES. These show a very high degree of preferred orientation and are particularly suitable for intercalation treatments. The term "vapour-grown carbon fibres" alternatively used in the literature is acceptable. The use of the term "CVD fibres" is not recommended as an alternative for GAS PHASE-GROWN CARBON FIBRES since the term "CVD fibres" also describes fibres grown by a chemical vapour deposition (CVD) process on substrate fibres.

See: GRAPHITE FIBRES  
GRAPHITIZATION HEAT TREATMENT

**GLASS-LIKE CARBON**

*Description:*

GLASS-LIKE CARBON is an AGRANULAR NON-GRAPHITIZABLE CARBON with a very high isotropy of its structural and physical properties and with a very low permeability for liquids and gases. The original surfaces and the fracture surfaces have a pseudo-glassy appearance.

See: AGRANULAR CARBON  
NON-GRAPHITIZABLE CARBON

*Note:*

The often used synonyms "Glassy Carbon" and "Vitreous Carbon" have been introduced as trademarks and should not be used as terms. From a scientific viewpoint, all synonymous terms suggest a similarity with the structure of silicate glasses which does not exist in GLASS-LIKE CARBON, except for the pseudo-glassy appearance of the surface.

GLASS-LIKE CARBON cannot be described as AMORPHOUS CARBON because it consists of two-dimensional structural elements and does not exhibit "dangling" bonds.

See: AMORPHOUS CARBON

## GRANULAR CARBON

### *Description:*

The term GRANULAR CARBON is equivalent to coarse PARTICULATE CARBON. This is a CARBON MATERIAL consisting of separate particles or grains which are monolithic, on the average larger than about 100  $\mu\text{m}$  in diameter, but smaller than about 1 cm.

See: CARBON MATERIAL  
PARTICULATE CARBON

### *Notes:*

Although limits of size cannot be exactly defined, coke grains obtained by grinding belong to coarse PARTICULATE CARBON for grain sizes above ca. 100  $\mu\text{m}$ , or to fine PARTICULATE CARBON for grain sizes below ca. 100  $\mu\text{m}$ . COLLOIDAL GRAPHITE obtained by grinding of NATURAL GRAPHITE is a typical extra fine PARTICULATE CARBON. Industrial CARBON MATERIALS (such as electrodes) are made with FILLERS composed of coarse PARTICULATE CARBON (coke grains) and fine PARTICULATE CARBON (flour), and sometimes even COLLOIDAL CARBON (CARBON BLACKS or SOOT). They are therefore poly-granular materials.

See: CARBON BLACK  
CARBON MATERIAL  
COLLOIDAL CARBON  
FILLER  
NATURAL GRAPHITE  
PARTICULATE CARBON  
SOOT

## GRAPHENE LAYER

### *Description:*

GRAPHENE is a single carbon layer of the graphite structure, describing its nature by analogy to a polycyclic aromatic hydrocarbon of quasi infinite size.

### *Notes:*

Previously, descriptions such as graphite layers, carbon layers or carbon sheets have been used for the term GRAPHENE.

Because GRAPHITE designates that modification of the chemical element CARBON, in which planar sheets of carbon atoms, each atom bound to three neighbours in a honeycomb-like structure, are stacked in a three-dimensional regular order, it is not correct to use for a single layer a term which includes the term GRAPHITE, which would imply a three-dimensional structure. The term GRAPHENE should be used only when the reactions, structural relations or other properties of individual layers are discussed.

See: CARBON  
GRAPHITE

## GRAPHITE

### *Description:*

GRAPHITE is an allotropic form of the element carbon consisting of layers of hexagonally arranged carbon atoms in a planar condensed ring system (GRAPHENE LAYERS). The layers are stacked parallel to each other in a three-dimensional crystalline long-range order. There are two allotropic forms with different stacking arrangements, hexagonal and rhombohedral. The chemical bonds within the layers are covalent with  $\text{sp}^2$  hybridization and with a C-C-distance of 141.7 pm. The weak bonds between the layers are metallic with a strength comparable to VAN DER WAALS bonding only.

See: CARBON  
HEXAGONAL GRAPHITE  
RHOMBOHEDRAL GRAPHITE

### *Note:*

The term GRAPHITE is also used often but incorrectly to describe GRAPHITE MATERIALS, i.e. materials consisting of GRAPHITIC CARBON made from CARBON MATERIALS by



processing to temperatures greater than 2500 K, even though no perfect graphite structure is present.

See: GRAPHITIC CARBON  
CARBON MATERIAL  
GRAPHITE MATERIAL

### GRAPHITE ELECTRODE

*Description:*

See: CARBON ELECTRODE

### GRAPHITE FIBRES

*Description:*

GRAPHITE FIBRES are CARBON FIBRES consisting mostly of SYNTHETIC GRAPHITE for which three-dimensional crystalline order is confirmed by X-ray diffraction.

See: CARBON FIBRES  
SYNTHETIC GRAPHITE

*Note:*

GRAPHITE FIBRES can be obtained by GRAPHITIZATION HEAT TREATMENT of CARBON FIBRES if these consist mostly of GRAPHITIZABLE CARBON. If the  $h,k,l$  diffraction lines are difficult to recognize because they are of minor intensity, the mean interlayer spacing  $c/2$  can be used as indication for the presence of a graphitic structure. The  $c/2$  value of 0.34 nm is generally considered as an upper limit for SYNTHETIC GRAPHITE.

See: CARBON FIBRES  
GRAPHITIZABLE CARBON  
GRAPHITIZATION HEAT TREATMENT  
SYNTHETIC GRAPHITE

### GRAPHITE MATERIAL

*Description:*

GRAPHITE MATERIAL is a material consisting essentially of GRAPHITIC CARBON.

See: GRAPHITE  
GRAPHITIC CARBON

*Note:*

The use of the term GRAPHITE as a short term for material consisting of GRAPHITIC CARBON is incorrect. The term GRAPHITE can only be used in combination with other nouns or clarifying adjectives for special types of GRAPHITE MATERIALS (graphite electrodes, NATURAL GRAPHITE and others). The use of the term GRAPHITE without a noun or clarifying adjective should be restricted to the allotropic form of the element CARBON:

See: CARBON  
GRAPHITE  
GRAPHITIC CARBON  
NATURAL GRAPHITE

### GRAPHITE WHISKER

*Description:*

GRAPHITE WHISKERS consist of thin, approximately cylindrical filaments in which GRAPHENE LAYERS are arranged in a scroll-like manner. There is, at least in part, a regular stacking of the layers as in the GRAPHITE lattice, giving rise to  $h,k,l$  X-ray reflections. The physical properties of GRAPHITE WHISKERS approach, along the cylinder axis, those of GRAPHITE.

*Note:*

If there is, due to misalignment of the layers caused by their bending, no three-dimensional stacking order as in GRAPHITE, the term CARBON WHISKERS should be used. GRAPHITE

WHISKERS and CARBON WHISKERS should be distinguished from more disordered FILAMENTIOUS CARBON.

See: FILAMENTOUS CARBON  
GRAPHITIC CARBON

### GRAPHITIC CARBON

*Description:*

GRAPHITIC CARBONS are all varieties of substances consisting of the element carbon in the allotropic form of GRAPHITE irrespective of the presence of structural defects.

See: GRAPHITE

*Note:*

The use of the term GRAPHITIC CARBON is justified if three-dimensional hexagonal crystalline long-range order can be detected in the material by diffraction methods, independent of the volume fraction and the homogeneity of distribution of such crystalline domains. Otherwise, the term NON-GRAPHITIC CARBON should be used.

See: NON-GRAPHITIC CARBON

### GRAPHITIZABLE CARBON

*Description:*

GRAPHITIZABLE CARBON is a NON-GRAPHITIC CARBON which upon GRAPHITIZATION HEAT TREATMENT converts into GRAPHITIC CARBON.

See: GRAPHITIC CARBON  
GRAPHITIZATION HEAT TREATMENT  
NON-GRAPHITIC CARBON

*Note:*

If it is preferred to define the characterizable state of material instead of its behaviour during subsequent treatment, the term "Pregraphitic Carbon" could be considered.

### GRAPHITIZATION

*Description:*

GRAPHITIZATION is a solid-state transformation of thermodynamically unstable NON-GRAPHITIC CARBON into GRAPHITE by means of heat treatment.

See: GRAPHITE  
NON-GRAPHITIC CARBON

*Note:*

GRAPHITIZATION is also used for the transformation of metastable DIAMOND into GRAPHITE by heat treatment, as well as in metallurgy for the formation of GRAPHITE from thermodynamically unstable carbides by thermal decomposition at high temperatures. Such uses of the term GRAPHITIZATION are in line with the above definition. The use of the term GRAPHITIZATION to indicate a process of thermal treatment of CARBON MATERIALS at  $T > 2500$  K regardless of any resultant crystallinity is incorrect.

See: CARBON MATERIALS  
DIAMOND  
GRAPHITE  
GRAPHITIZATION  
GRAPHITIZATION HEAT TREATMENT

### GRAPHITIZATION HEAT TREATMENT

*Description:*

GRAPHITIZATION HEAT TREATMENT is a process of heat treatment of a NON-GRAPHITIC CARBON, industrially performed at temperatures in the range between 2500 K and 3300 K, to achieve transformation into GRAPHITIC CARBON.

See: GRAPHITIC CARBON  
GRAPHITIZATION  
NON-GRAPHITIC CARBON

*Note:*

The term GRAPHITIZATION HEAT TREATMENT does not include information as to the crystallinity achieved by the heat treatment, that is the extent of transformation into GRAPHITIC CARBON or the degree of GRAPHITIZATION. Only for such a transformation into GRAPHITIC CARBON should the term GRAPHITIZATION be used. Consequently: the common use of the term GRAPHITIZATION for the heat treatment process only, regardless of the resultant crystallinity, is incorrect and should be avoided.

See: GRAPHITIC CARBON  
GRAPHITIZATION

**GRAPHITIZED CARBON***Description:*

GRAPHITIZED CARBON is a GRAPHITIC CARBON with more or less perfect three-dimensional hexagonal crystalline order prepared from NON-GRAPHITIC CARBON by GRAPHITIZATION HEAT TREATMENT:

See: GRAPHITIC CARBON  
GRAPHITIZATION HEAT TREATMENT  
NON-GRAPHITIC CARBON

*Note:*

NON-GRAPHITIZABLE CARBONS do not transform into GRAPHITIC CARBON on heat treatment at temperatures above 2500 K and therefore are not GRAPHITIZED CARBONS.

See: GRAPHITIZABLE CARBON  
NON-GRAPHITIZABLE CARBON

**GREEN COKE***Description:*

GREEN COKE (RAW COKE) is the primary solid CARBONIZATION product from high boiling hydrocarbon fractions obtained at temperatures below 900 K. It contains a fraction of matter that can be released as volatiles during subsequent heat treatment at temperatures up to approximately 1600 K. This mass fraction, the so-called volatile matter, is in the case of GREEN COKE between 4 and 15 wt.%, but it depends also on the heating rate.

See: CARBONIZATION  
RAW COKE

*Note:*

RAW COKE is an equivalent term to GREEN COKE although it is now less frequently used. The so-called volatile matter of GREEN COKE depends on temperature and time of coking, but also on the method for its determination.

See: RAW COKE

**HARD AMORPHOUS CARBON FILMS***Description:*

HARD AMORPHOUS CARBON FILMS is a synonym for DIAMOND-LIKE CARBON FILMS.

See: DIAMOND-LIKE CARBON FILMS.

**HEXAGONAL GRAPHITE***Description:*

HEXAGONAL GRAPHITE is the thermodynamically stable form of GRAPHITE with an ABAB stacking sequence of the GRAPHENE LAYERS. The exact crystallographic description of this allotropic form is given by the space group  $D6h^4 - P6_3/mmc$  (unit cell constants:  $a = 245.6$  pm,  $c = 670.8$  pm). HEXAGONAL GRAPHITE is thermodynamically stable below approximately 2600 K and 6 GPa.

See: GRAPHITE

*Note:*

The use of the term GRAPHITE instead of the more exact term HEXAGONAL GRAPHITE may be tolerated in view of the minor importance of RHOMBOHEDRAL GRAPHITE, the other allotropic form.

See: GRAPHITE  
RHOMBOHEDRAL GRAPHITE

**HIGH-PRESSURE GRAPHITIZATION***Description:*

HIGH-PRESSURE GRAPHITIZATION refers to a solid-state transformation of NON-GRAPHITIC CARBON into GRAPHITE by heat treatment under elevated pressure (e.g. 100 to 1000 MPa) so that a definitely higher degree of GRAPHITIZATION is achieved at lower temperature and/or for a shorter heat treatment time than in heat treatment of the same NON-GRAPHITIC material at atmospheric pressure.

See: GRAPHITE  
GRAPHITIZATION  
NON-GRAPHITIC CARBON

**HIGHLY ORIENTED PYROLYTIC GRAPHITE***Description:*

HIGHLY ORIENTED PYROLYTIC GRAPHITE (HOPG) is a PYROLYTIC GRAPHITE with an angular spread of the c-axes of the crystallites of less than 1 degree.

See: GRAPHITE  
PYROLYTIC GRAPHITE

*Note:*

Commercial HIGHLY ORIENTED PYROLYTIC GRAPHITE is usually produced by stress annealing at approximately 3300 K.

**ISOTROPIC CARBON***Description:*

ISOTROPIC CARBON is a monolithic CARBON MATERIAL without preferred crystallographic orientation of the microstructure.

See: CARBON MATERIAL

*Note:*

ISOTROPIC CARBON can also be a GRAPHITE MATERIAL. The isotropy can be gross (bulk), macroscopic, or microscopic, depending on the structural level at which isotropy is obtained. This word is widely used today and its meaning covers all the above levels. For example, the aerospace graphites have isotropy built in by random grain orientation. Some NUCLEAR GRAPHITES are isotropic at the crystalline (sub-grain) level.

See: GRAPHITE MATERIAL  
NUCLEAR GRAPHITE

**ISOTROPIC PITCH-BASED CARBON FIBRES***Description:*

ISOTROPIC PITCH-BASED CARBON FIBRES are CARBON FIBRES obtained by CARBONIZATION of isotropic pitch fibres after these have been stabilized (i.e., made non-fusible).

See: CARBON FIBRES  
CARBONIZATION  
PITCH-BASED CARBON FIBRES  
STABILIZATION TREATMENT

*Notes:*

During fabrication of ISOTROPIC PITCH-BASED CARBON FIBRES no means (neither mechanical nor chemical) are applied to achieve preferred orientation of the polyaromatic molecules in the fibre direction. They belong to the CARBON FIBRES TYPE LM (Low Modu-

lus), and because of the relatively low values of strength and Young's modulus this PITCH-BASED CARBON FIBRE type is not used for high-performance reinforcement purposes.

See: CARBON FIBRES TYPE LM  
PITCH-BASED CARBON FIBRES

### LAMP BLACK

*Description:*

LAMP BLACK is a special type of CARBON BLACK produced by incomplete combustion of a fuel rich in aromatics that is burned in flat pans. LAMP BLACK is characterized by a relatively broad particle size distribution.

See: CARBON BLACK

### MESOGENIC PITCH

*Description:*

MESOGENIC PITCH is a PITCH with a complex mixture of numerous essentially aromatic hydrocarbons. It does not contain anisotropic particles detectable by optical microscopy. MESOGENIC PITCH is low in quinoline-insoluble fractions and capable of transforming into MESOPHASE PITCH during continuous heat treatment above 750 K by the formation of optically detectable CARBONACEOUS MESOPHASE.

See: CARBONACEOUS MESOPHASE  
MESOPHASE PITCH  
PITCH

### MESOPHASE PITCH

*Description:*

MESOPHASE PITCH is a PITCH with a complex mixture of numerous essentially aromatic hydrocarbons containing anisotropic liquid-crystalline particles (CARBONACEOUS MESOPHASE) detectable by optical microscopy and capable of coalescence into the BULK MESOPHASE.

See: BULK MESOPHASE  
CARBONACEOUS MESOPHASE  
MESOGENIC PITCH  
PITCH

*Notes:*

The CARBONACEOUS MESOPHASE particles are formed from the aromatics of high molecular mass in MESOGENIC PITCH, which have not yet been aggregated to particles detectable by optical microscopy within the apparently isotropic PITCH matrix. The CARBONACEOUS MESOPHASE is insoluble in quinoline and pyridine, but the amount of mesophase measured from microscopical observation appears somewhat higher because parts of the CARBONACEOUS MESOPHASE can be extracted by the solvents.

See: CARBONACEOUS MESOPHASE  
MESOGENIC PITCH  
PITCH

### MESOPHASE PITCH-BASED CARBON FIBRES

*Description:*

MESOPHASE PITCH-BASED CARBON FIBRES (MPP-BASED CARBON FIBRES) are CARBON FIBRES obtained from MESOGENIC PITCH after it has been transformed into MESOPHASE PITCH (MPP) at least during the process of spinning, and after the spun MESOPHASE PITCH fibres have been made non-fusible (stabilized) and carbonized.

See: CARBON FIBRES  
MESOGENIC PITCH  
MESOPHASE PITCH  
PITCH  
PITCH-BASED CARBON FIBRES

**METALLURGICAL COKE***Description:*

METALLURGICAL COKE is produced by CARBONIZATION of coals or coal blends at temperatures up to 1400 K to produce a macroporous CARBON MATERIAL of high strength and relatively large lump size.

See: CARBON MATERIAL  
CARBONIZATION

*Notes:*

METALLURGICAL COKES must have a high strength to support heavy loads in the blast furnace without disintegration. METALLURGICAL COKE is also used as FILLER COKE for POLYGRANULAR CARBON products.

See: FILLER COKE  
POLYGRANULAR CARBON

**MICROPOROUS CARBON***Description:*

MICROPOROUS CARBON is a porous CARBON MATERIAL, usually a CHAR or CARBON FIBRES, which may or may not have been subjected to an activation process to increase its adsorptive properties. A MICROPOROUS CARBON is considered to have a major part of its porosity in pores of less than 2 nm width and to exhibit apparent surface areas usually higher than 200 to 300 m<sup>2</sup>·g<sup>-1</sup>.

See: ACTIVATED CARBON  
FIBRIOUS ACTIVATED CARBON

*Notes:*

For definition of micropores see: IUPAC Manual of Symbols and Terminology, Appendix 2, Pt.1, Colloid and Surface Chemistry. *Pure Appl.Chem.* **31**, 518 (1972).

The surface areas determined by the Brunauer-Emmett-Teller (BET) method are apparent surface areas only since the BET adsorption equation is, in principle, not valid when micropore filling occurs. The determination of the true surface area in the micropores depends on the method used for the evaluation of the adsorption isotherms and on the model used for the shape of the micropores (cylindrical, slit-shaped or other).

**MPP-BASED CARBON FIBRES***Description:*

See: MESOPHASE PITCH-BASED CARBON FIBRES

**NATURAL GRAPHITE***Description:*

NATURAL GRAPHITE is a mineral found in nature. It consists of GRAPHITIC CARBON regardless of its crystalline perfection.

See: GRAPHITIC CARBON

*Notes:*

Some NATURAL GRAPHITES, often in the form of large flakes, show very high crystalline perfection. Occasionally, they occur as single crystals of GRAPHITE. The use of the term NATURAL GRAPHITE as a synonym for the term "Graphite Single Crystal" is incorrect and should be avoided. Varieties of NATURAL GRAPHITE with lower structural perfection are classified as "Microcrystalline NATURAL GRAPHITE". Commercial NATURAL GRAPHITE is often contaminated with other minerals, e.g. silicates, and may contain RHOMBOHEDRAL GRAPHITE due to intensive milling.

See: GRAPHITE  
RHOMBOHEDRAL GRAPHITE

**NEEDLE COKE***Description:*

NEEDLE COKE is the commonly used term for a special type of COKE with extremely high

graphitizability resulting from a strong preferred parallel orientation of its turbostratic layer structure and a particular physical shape of the grains.

See: COKE

*Notes:*

NEEDLE COKE is derived mainly from clean (*i.e.* lacking hetero atoms and solids) and highly aromatic (*i.e.* several condensed rings per cluster) feedstocks with a very low concentration of insolubles. Upon solidification a material with a distinctive streaked or flow-like macroscopic appearance is produced. Upon grinding the COKE breaks up first into macroscopic needles and then, after further grinding, into microplatelets. Sometimes the word "acicular" is used as a synonym for needle-like.

See: COKE

DELAYED COKING PROCESS

### NON-GRAPHITIC CARBON

*Description:*

NON-GRAPHITIC CARBONS are all varieties of solids consisting mainly of the element carbon with two-dimensional long-range order of the carbon atoms in planar hexagonal networks, but without any measurable crystallographic order in the third direction (*c*-direction) apart from more or less parallel stacking.

See: AMORPHOUS CARBON

*Note:*

Some varieties of NON-GRAPHITIC CARBON convert on heat treatment to GRAPHITIC CARBON (GRAPHITIZABLE CARBON) but some others do not (NON-GRAPHITIZABLE CARBON).

See: GRAPHITIC CARBON

GRAPHITIZABLE CARBON

NON-GRAPHITIC CARBON

NON-GRAPHITIZABLE CARBON

### NON-GRAPHITIZABLE CARBON

*Description:*

NON-GRAPHITIZABLE CARBON is a NON-GRAPHITIC CARBON which cannot be transformed into GRAPHITIC CARBON solely by high-temperature treatment up to 3300 K under atmospheric pressure or lower pressure.

See: GRAPHITIC CARBON

GRAPHITIZATION HEAT TREATMENT

NON-GRAPHITIC CARBON

*Note:*

The term NON-GRAPHITIZABLE is limited to the result of heat treatment without additional influence of foreign matter or neutron radiation. NON-GRAPHITIZABLE CARBON can be transformed into GRAPHITIC CARBON by a high-temperature process via intermediate dissolution in foreign matter and precipitation under high pressure or by radiation damage.

See: GRAPHITIC CARBON

### NUCLEAR GRAPHITE

*Description:*

NUCLEAR GRAPHITE is a POLYGRANULAR GRAPHITE material for use in nuclear reactor cores consisting of GRAPHITIC CARBON of very high chemical purity. High purity is needed to avoid absorption of low-energy neutrons and the production of undesirable radioactive species.

See: GRAPHITE MATERIAL

GRAPHITIC CARBON

POLYGRANULAR GRAPHITE

*Notes:*

Apart from the absence of neutron-absorbing impurities, modern reactor graphites are also characterized by a high degree of GRAPHITIZATION and no preferred bulk orientation. Such properties increase the dimensional stability of the NUCLEAR GRAPHITE at high temperatures and in a high flux of neutrons. The term NUCLEAR GRAPHITE is often, but incorrectly, used for any GRAPHITE MATERIAL in a nuclear reactor, even if it serves only for structural purposes.

See: GRAPHITE MATERIAL  
GRAPHITIZATION

**PAN-BASED CARBON FIBRES***Description:*

PAN-PASED CARBON FIBRES are CARBON FIBRES obtained from polyacrylonitrile (PAN) precursor fibres by STABILIZATION TREATMENT, CARBONIZATION, and final heat treatment.

See: CARBON FIBRES  
CARBONIZATION  
STABILIZATION TREATMENT

**PARTICULATE CARBON***Description:*

PARTICULATE CARBON is a CARBON MATERIAL consisting of separated monolithic particles.

See: CARBON MATERIAL

*Note:*

Distinctions should be made between coarse PARTICULATE CARBON or GRANULAR CARBON (larger than about 100  $\mu\text{m}$ , but smaller than about 1 cm in average size), fine PARTICULATE CARBON or powder or flour (between 1  $\mu\text{m}$  and 100  $\mu\text{m}$  in average size) and COLLOIDAL CARBON (below approximately 1  $\mu\text{m}$  in size in at least one direction), e.g. CARBON BLACKS and COLLOIDAL CARBON.

See: CARBON BLACK  
COLLOIDAL CARBON  
GRANULAR CARBON  
PARTICULATE CARBON

**PETROLEUM COKE***Description:*

PETROLEUM COKE is a CARBONIZATION product of high-boiling hydrocarbon fractions obtained in petroleum processing (heavy residues). It is the general term for all special PETROLEUM COKE products such as GREEN, CALCINED and NEEDLE petroleum COKE.

See: CALCINED COKE  
CARBONIZATION  
GREEN or RAW COKE  
NEEDLE COKE

*Note:*

High-boiling hydrocarbon fractions (heavy residues) used as feedstock for PETROLEUM COKE are residues from distillation (atmospheric pressure, vacuum) or cracking (e.g. thermal, catalytic, steam-based) processes. The nature of feedstock has a decisive influence on the graphitizability of the CALCINED COKE.

See: CALCINED COKE

**PETROLEUM PITCH***Description:*

PETROLEUM PITCH is a residue from heat treatment and distillation of petroleum fractions. It is solid at room temperature, consists of a complex mixture of numerous predominantly



aromatic and alkyl-substituted aromatic hydrocarbons, and exhibits a broad softening range instead of a defined melting temperature.

*Note:*

The hydrogen aromaticity (ratio of aromatic to total hydrogen atoms) varies between 0.3 and 0.6. The aliphatic hydrogen atoms are typically present in alkyl groups substituted on aromatic rings or as naphthenic hydrogen.

## PITCH

*Description:*

PITCH is a residue from pyrolysis of organic material or tar distillation which is solid at room temperature, consisting of a complex mixture of numerous, essentially aromatic hydrocarbons and heterocyclic compounds. It exhibits a broad softening range instead of a defined melting temperature. When cooled from the melt, pitches solidify without crystallization.

*Notes:*

The ratio of aromatic to aliphatic hydrogen depends mainly on the source of the starting material. The hydrogen aromaticity (ratio of aromatic to total hydrogen atoms) varies between 0.3 and 0.9.

The aliphatic hydrogen in pitch is largely associated with alkyl side chains substituted on aromatic rings. The content of heterocyclic compounds in pitches varies depending on their origins. Also the softening temperature can vary in a broad range between about 320 K and 570 K depending on the molecular weight (relative molecular mass) and composition of the constituents.

## PITCH-BASED CARBON FIBRES

*Description:*

PITCH-BASED CARBON FIBRES are CARBON FIBRES obtained from PITCH precursor fibres after STABILIZATION TREATMENT, CARBONIZATION, and final heat treatment.

See: CARBON FIBRES  
PITCH  
STABILIZATION TREATMENT

*Notes:*

The term PITCH-BASED CARBON FIBRES comprises the ISOTROPIC PITCH-BASED CARBON FIBRES as well as the anisotropic MESOPHASE PITCH-BASED CARBON FIBRES (MPP-BASED CARBON FIBRES). The isotropic type belongs to the CARBON FIBRES TYPE LM (Low Modulus) and is mainly used as filler in polymers and insulation materials and for similar applications. The anisotropic type (MPP-BASED CARBON FIBRES) belongs to the CARBON FIBRES TYPE HM and is used mainly for reinforcement purposes due to its high Young's modulus value.

See: CARBON FIBRES TYPE HM  
CARBON FIBRES TYPE LM  
ISOTROPIC PITCH-BASED CARBON FIBRES  
MESOPHASE PITCH-BASED CARBON FIBRES

## POLYCRYSTALLINE GRAPHITE

*Description:*

POLYCRYSTALLINE GRAPHITE is a GRAPHITE MATERIAL with coherent crystallographic domains of limited size regardless of the perfection and preferred orientation (texture) of their crystalline structure.

See: GRAPHITE MATERIAL

*Notes:*

The common use of the term POLYCRYSTALLINE GRAPHITE for POLYGRANULAR GRAPHITE is in line with this definition but may be inexact because usually all grains of POLYGRANULAR GRAPHITE are polycrystalline themselves. - POLYCRYSTALLINE

GRAPHITE can exhibit a random orientation, more or less preferred orientation, or a highly oriented texture as in some PYROLYTIC GRAPHITES. There is no sharp transition, however, between the typical polycrystalline texture and the "single crystal-like" texture of HIGHLY ORIENTED PYROLYTIC GRAPHITE (HOPG).

See: HIGHLY ORIENTED PYROLYTIC GRAPHITE  
POLYGRANULAR GRAPHITE  
PYROLYTIC GRAPHITE

### **POLYGRANULAR CARBON**

*Description:*

POLYGRANULAR CARBON is a CARBON MATERIAL composed of grains, which can be clearly distinguished by means of optical microscopy.

See: CARBON MATERIAL

*Note:*

Industrial CARBON MATERIALS (such as electrodes) are mostly polygranular, but special grades are agranular materials, such as GLASS-LIKE CARBON, CARBON FIBRES or PYROLYTIC CARBON. Such materials are covered by the term AGRANULAR CARBON.

See: AGRANULAR CARBON  
CARBON FIBRES  
CARBON MATERIAL  
GLASS-LIKE CARBON  
PYROLYTIC CARBON

### **POLYGRANULAR GRAPHITE**

*Description:*

POLYGRANULAR GRAPHITE is a GRAPHITE MATERIAL composed of grains which can be clearly distinguished by means of optical microscopy.

See: GRAPHITE MATERIAL

*Note:*

From the viewpoint of crystallinity, a POLYGRANULAR GRAPHITE is always a POLYCRYSTALLINE GRAPHITE, but not vice versa. Most industrial GRAPHITE MATERIALS are polygranular. Monogranular materials consist mostly of NON-GRAPHITIC CARBON, such materials are called monolithic or AGRANULAR CARBONS.

See: AGRANULAR CARBON  
GRAPHITE MATERIAL  
NON-GRAPHITIC CARBON  
POLYCRYSTALLINE GRAPHITE

### **PREMIUM COKE**

*Description:*

PREMIUM COKE is an extremely well graphitizing carbon with a high degree of optical anisotropy (isochromatic areas of optical texture above about 100  $\mu\text{m}$ ) and is characterized by a combination of the following properties which differ significantly from those of REGULAR COKE: high real density, low reversible thermal expansion, and low ash content combined, in most cases, with low sulfur content.

See: REGULAR COKE

*Note:*

PREMIUM COKE is mainly produced from tars or residues from petrochemistry by the DELAYED COKING PROCESS. Also refined COAL TAR PITCHES are used as precursors for PREMIUM COKE production.

See: COAL TAR PITCH  
DELAYED COKING PROCESS  
REGULAR COKE

**PUFFING***Description:*

The term PUFFING describes an irreversible expansion of some CARBON ARTIFACTS during GRAPHITIZATION HEAT TREATMENT between 1650 K and 2700 K.

See: CARBON ARTIFACT  
COKE  
GRAPHITIZATION HEAT TREATMENT

*Note:*

PUFFING is caused by the release of heteroatoms, for instance sulfur atoms, from the COKE in association with specific microstructural rearrangements.

See: COKE  
POLYGRANULAR CARBON  
PUFFING INHIBITOR

**PUFFING INHIBITOR***Description:*

PUFFING INHIBITORS are metals or metal compounds with a high chemical affinity for the heteroatoms in the carbons. They are distributed as fine particles within the CARBON MATERIALS to be graphitized.

See: CARBON MATERIAL

*Note:*

Iron and iron compounds are most frequently used as PUFFING INHIBITORS when PUFFING is related to sulfur.

See: PUFFING

**PYROLYTIC CARBON***Description:*

PYROLYTIC CARBON is a CARBON MATERIAL deposited from gaseous hydrocarbon compounds on suitable underlying substrates (CARBON MATERIALS, metals, ceramics) at temperatures ranging from 1000 K to 2500 K (chemical vapour deposition).

See: CARBON MATERIAL

*Notes:*

A wide range of microstructures, e.g. isotropic, lamellar, substrate-nucleated and a varied content of remaining hydrogen, can occur in PYROLYTIC CARBONS, depending on the deposition conditions (temperature, type, concentration and flow rate of the source gas, surface area of the underlying substrate, etc.).

"Pyrocarbon" which is synonymous with PYROLYTIC CARBON was introduced as a trademark and should not be used as a term.

The term PYROLYTIC CARBON does not describe the large range of CARBON MATERIALS obtained by thermal degradation (thermolysis, pyrolysis) of organic compounds when they are not formed by chemical vapour deposition (CVD). Also CARBON MATERIALS, obtained by physical vapour deposition (PVD) are not covered by the term PYROLYTIC CARBON.

See: CARBON MATERIAL

**PYROLYTIC GRAPHITE***Description:*

PYROLYTIC GRAPHITE is a GRAPHITE MATERIAL with a high degree of preferred crystallographic orientation of the c-axes perpendicular to the surface of the substrate, obtained by GRAPHITIZATION HEAT TREATMENT of PYROLYTIC CARBON or by chemical vapour deposition at temperatures above 2500 K.

See: GRAPHITE MATERIAL  
GRAPHITIZATION HEAT TREATMENT  
PYROLYTIC CARBON

**Notes:**

"Pyrographite", a synonym for PYROLYTIC GRAPHITE, was introduced as a trademark and should not be used as term.

Hot working of PYROLYTIC GRAPHITE (by heat treatment under compressive stress at temperatures above 3000 K) results in HIGHLY ORIENTED PYROLYTIC GRAPHITE (HOPG).

See: HIGHLY ORIENTED PYROLYTIC GRAPHITE

**RAW COKE****Description:**

See: GREEN COKE

**Note:**

The term RAW COKE is equivalent to GREEN COKE although it now used less frequently.

**RAYON-BASED CARBON FIBRES****Description:**

RAYON-BASED CARBON FIBRES are CARBON FIBRES made from rayon (cellulose) precursor fibres.

See: CARBON FIBRES

**Notes:**

RAYON-BASED CARBON FIBRES have a more isotropic structure than similarly heat-treated polyacrylonitrile (PAN)- or MESOPHASE PITCH (MPP)-BASED CARBON FIBRES. Their Young's modulus values are therefore drastically lower ( $E^a) < 100$  GPa,  $\sigma^b) > 100$  MPa). RAYON-BASED CARBON FIBRES can be transformed into anisotropic CARBON FIBRES with high strength and Young's modulus values by hot-stretching treatment at temperatures of approximately 2800 K.

See: CARBON FIBRES

PAN-BASED CARBON FIBRES

MESOPHASE PITCH-BASED CARBON FIBRES

<sup>a)</sup>  $E$ , Young's modulus

<sup>b)</sup>  $\sigma$ , tensile strength

**REGULAR COKE****Description:**

REGULAR COKE is a PETROLEUM COKE with good graphitizability and is characterized by a combination of properties which differ significantly from those of METALLURGICAL COKE but do not reach the quality level of PREMIUM COKE: These properties are: optical anisotropy, medium reversible thermal expansion, and low ash content.

See: METALLURGICAL COKE

PETROLEUM COKE

PREMIUM COKE

**Notes:**

Typical characteristics for REGULAR COKE in comparison with those of METALLURGICAL COKE and of PREMIUM COKE calcined at 1620 K are:

		Regular Coke	Premium Coke	Metallurgical Coke
Real density <sup>a)</sup>	(g·cm <sup>-3</sup> )	2.07 - 2.09	2.12 - 2.14	1.95 - 2.02
CTE <sup>b)</sup> (293-773 K)	(K <sup>-1</sup> )	$2.0 \cdot 10^{-6}$	$1.1 \cdot 10^{-6}$	$>3.0 \cdot 10^{-6}$
CTE <sup>b)</sup> (293-773 K)	(K <sup>-1</sup> )	$1.0 \cdot 10^{-6}$	$0.5 \cdot 10^{-6}$	$2.0 \cdot 10^{-6}$
Ash	(wt.%)	0.4	0.05	8 - 12
Sulfur	(wt.%)	1.0 - 1.5	0.6	0.6 - 5.0

<sup>a)</sup> measured with *m*-xylene

<sup>b)</sup> coefficient of thermal expansion

REGULAR COKE is mainly used for the production of SYNTHETIC CARBON and GRAPHITE MATERIALS.

See: CARBON MATERIAL  
GRAPHITE MATERIAL  
METALLURGICAL COKE  
PREMIUM COKE  
SYNTHETIC GRAPHITE

### RHOMBOHEDRAL GRAPHITE

*Description:*

RHOMBOHEDRAL GRAPHITE is a thermodynamically unstable allotropic form of GRAPHITE with an ABCABC stacking sequence of the layers. The exact crystallographic description of this allotropic form is given by the space group  $D3d^5 - R\bar{3}m$ , (unit cell constants:  $a = 256.6$  pm,  $c = 1006.2$  pm).

See: GRAPHITE

*Notes:*

The structure of RHOMBOHEDRAL GRAPHITE can be best considered as an extended stacking fault in HEXAGONAL GRAPHITE. RHOMBOHEDRAL GRAPHITE can not be isolated in pure form (NATURAL GRAPHITE and laboratory preparations contain less than 40% of RHOMBOHEDRAL GRAPHITE in combination with HEXAGONAL GRAPHITE). It is produced by shear deformation of HEXAGONAL GRAPHITE and transforms progressively to the hexagonal (ABAB) modification on heating above 1600 K.

See: HEXAGONAL GRAPHITE  
NATURAL GRAPHITE

### SEMIKOKE

*Description:*

SEMIKOKE is a carbonaceous material intermediate between a fusible mesophase pitch and a non-deformable GREEN COKE produced by incomplete CARBONIZATION at temperatures between the onset of fusion (of coal, ca. 620 K), and complete devolatilization. SEMIKOKE still contains volatile matter, therefore.

See: CARBONIZATION  
COAL TAR PITCH  
GREEN COKE

*Note:*

SEMIKOKE may be conceived as covering a continuous range from coal that has not yet been fused to COKE BREEZE. SEMIKOKE can also be used as a FILLER in carbon mixtures.

See: COKE BREEZE  
FILLER

### SOOT

*Description:*

SOOT is a randomly formed PARTICULATE CARBON material and may be coarse, fine, and/or colloidal in proportions dependent on its origin. SOOT consists of variable quantities of carbonaceous and inorganic solids together with absorbed and occluded tars and resins.

See: PARTICULATE CARBON

*Notes:*

SOOT is generally formed as an unwanted by-product of incomplete combustion or pyrolysis. SOOT generated within flames consists essentially of aggregates of spheres of carbon. SOOT found in domestic fireplace chimneys contains few aggregates but may contain substantial amounts of particulate fragments of COKE or CHAR. SOOT from diesel engines consists essentially of aggregates together with tars and resins. For historical reasons, the term SOOT is sometimes incorrectly used for CARBON BLACK. This misleading use should be avoided.

See: CARBON BLACK  
CHAR  
COKE

### SPHERICAL CARBONACEOUS MESO-PHASE

*Description:*

The term SPHERICAL CARBONACEOUS MESOPHASE describes the morphology of CARBONACEOUS MESOPHASE which is formed in the isotropic PITCH matrix. The SPHERICAL CARBONACEOUS MESOPHASE usually has a lamellar structure consisting of flat aromatic molecules arranged in parallel layers which are perpendicular to the sphere/isotropic phase interface as described by BROOKS AND TAYLOR. On coalescence, this spherical mesophase loses its characteristic morphology and is converted to the BULK MESOPHASE.

See: BROOKS AND TAYLOR STRUCTURE  
BULK MESOPHASE  
CARBONACEOUS MESOPHASE  
PITCH

### STABILIZATION TREATMENT OF THERMOPLASTIC PRECURSOR FIBRES FOR CARBON FIBRES

*Description:*

STABILIZATION TREATMENT is a process applied to fusible organic precursor fibres for CARBON FIBRES with the aim of obtaining non-fusible polymer fibres suitable for subsequent CARBONIZATION. The original fibre shape is maintained.

See: CARBON FIBRES  
CARBONIZATION

*Notes:*

The STABILIZATION TREATMENT of thermoplastic precursor fibres for CARBON FIBRES is usually a heat treatment process performed in an oxidizing atmosphere above 470 K. For STABILIZATION TREATMENT of polyacrylonitrile (PAN) fibres, 600 K is the highest temperature up to which cyclization, dehydrogenation and oxidation processes prevail.

See: CARBON FIBRES

### STRESS GRAPHITIZATION

*Description:*

STRESS GRAPHITIZATION refers to the solid-state transformation of NON-GRAPHITIC CARBON into GRAPHITE by heat treatment combined with application of mechanical stress, resulting in a defined degree of GRAPHITIZATION being obtained at a lower temperature and/or after a shorter time of heat treatment than in the absence of applied stress.

See: GRAPHITE  
GRAPHITIZATION  
NON-GRAPHITIC CARBON

*Note:*

STRESS GRAPHITIZATION may also occur in volume elements of a carbon body in the process of heat treatment as a result of the action of internal residual or thermal stresses.

### SYNTHETIC GRAPHITE

*Description:*

SYNTHETIC GRAPHITE is a material consisting of GRAPHITIC CARBON which has been obtained by graphitizing of NON-GRAPHITIC CARBON, by chemical vapour deposition (CVD) from hydrocarbons at temperatures above 2500 K, by decomposition of thermally unstable carbides or by crystallizing from metal melts supersaturated with carbon.

See: GRAPHITIC CARBON  
GRAPHITIZATION  
NON-GRAPHITIC CARBON

*Notes:*

The term ARTIFICIAL GRAPHITE is often used as a synonym for SYNTHETIC GRAPHITE. The term SYNTHETIC GRAPHITE is preferred, however, since graphite crystals can be considered to consist of carbon macromolecules. Although the term SYNTHETIC GRAPHITE also covers the CVD product PYROLYTIC GRAPHITE as well as the residues of carbide decomposition, it is predominantly used for GRAPHITIZED CARBON. Such common use is in line with the above definition. Synonyms for this most important type of SYNTHETIC GRAPHITE are ACHESON GRAPHITE and ELECTROGRAPHITE.

See: ACHESON GRAPHITE  
ARTIFICIAL GRAPHITE  
ELECTROGRAPHITE  
GRAPHITIZED CARBON  
PYROLYTIC GRAPHITE

**THERMAL BLACK***Description:*

THERMAL BLACK is a special type of CARBON BLACK produced by pyrolysis of gaseous hydrocarbons in a preheated chamber in the absence of air. THERMAL BLACK consists of relatively large individual spheres (100 - 500 nm diameter) and aggregates of a small number of pseudospherical particles. The preferred alignment of the layer planes is parallel to the surface of the spheres.

See: CARBON BLACK

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